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REVIEW OF RESEARCH REACTOR ACTIVITIES IN THE SOVIET UNION

by V.V.Goncharov

Several types of experimental reactors with thermal neutron fluxes ranging from 10^{13} to 10^{14} n/cm^{2}sec have been created in the USSR. Among these are:

1. A 2000kW WWR-2 reactor with a neutron flux of $3 \cdot 10^{13}$ n/cm^{2}sec
2. A 2000 kW WWR-C reactor with a neutron flux of $2.5 \cdot 10^{13}$ n/cm^{2}sec.
3. A 2000 kW IRT reactor with a neutron flux of $3.2 \cdot 10^{13}$ n/cm^2 sec.
4. A 2500 kW HWR reactor with a neutron flux of $2.5 \cdot 10^{13}$ n/cm^{2}sek.
5. A HWR-C reactor with the output of up to 10,000 kW, and a neutron flux of $6 \cdot 10^{13}$ n/cm^2 sec.
6. Physical and technical research reactor PTR with the power of 15,000 kW and a neutron flux of $1.8 \cdot 10^{14}$ n/cm^2 sec.
7. Reactors WWR-2, WWR-C, IRT, WWR-M, WWR-Z and WWR-K are variants of the same basic design of the water moderated reactor. The construction and operating experience we have accumulated demonstrate their considerable advantages. They are simple in design and safe in operation convenient for carring out experiments. Besides initial investment and operating expenses are ralatively low. They provide sufficient neutron fluxes at moderate output. These qualities made water moderated reactors, WWR-C and IRT reactors in particular so widespread.

The construction of experimental reactors in a number of Union Republics of the USSR called to life new scientific centres on the basis of local scientific schools. Wide-scale investigations in various fields of physics, technology, chemistry, radiology and medicine are being performed there. Numerous research and technical institutes in these areas actively participate in the work of atomic centres utilising capacities of research reactors to the full.

Here are major trends of work conducted in some of the centres employing reactors with neutron fluxes of 10^{13} . 10^{14} n/cm^2 sec:

The WWR-M reactor in Leningrad is used for research work in nuclear physics (spectroscopy, isomerism, physics of fission), physics of solids (study of the magnetic state of a substance by means of polarised neutrons, neutronography of magnetic and semiconductor materials, investigation of the dynamics of a substance in a condensed state with the help of inelastic scattering of neutrons, radiation physics of semiconductor), radiobiology, radiochemistry (development of methods of enrichment and eduction of rare short-lived isotopes for nuclear and semiconductor research, investigation of chemical processes, taking place during nuclear transformations) and nuclear engineering too. Fourteen engaged institutions are participating in research there.

In Kiev 15 institutions carry out research on WWR-M reactor in nuclear physics (nuclear spectroscopy, neutron physics, physics of fission), solid - and liquid - state physics (neutron scattering in water-containing substances, neutronography of alloys, the effect of radiation on semiconductors) and in radiobiology (tissue dosimetry, the effect of radiation of microbiological samples).

In the Tbilisi atomic centre with its IRT reactor 25 institutions are engaged in

investigations into the physics of low temperatures, low temperature radiation study of materials, chemistry of hot atoms, radio chemistry, radiobiology and radiation selection

In Minsk II research organizations are conducting their scientific work in nuclear spectrogropy, solid-state physics (semiconductors, magnetic alloys) radio chemistry and radiobiology.

The Riga IRT reactor is employed for research in the field of solid-state physics (radiation phenomena in ion crystals), nuclear physics (spectroscopy, physics and chemistry of radiation and radiobiology.

Research workers in Tashkent tackled the activation analysis on the WWR-C reactor (determining rare and scattered elements in rocks and minerals, improving and developing new methods of activation analysis of semiconductors and other materials and also of the activation analysis of biological samples) along with chemical-dosimetry.

IRT and WWR-2 reactors in Moscow are used for broad-scale research in nuclear physics (investigation of the spectra of thermal capture γ-rays, physics of fission, neutron spectroscopy, in the neutron thermalisation field, solid and liquid-state physics (investigation of dynamics of the condensed state, neutronography, radiations physics), in nuclear engineering, into radiolysis of organic coolents and in radiobiology too.

The HWR reactor in Moscow is used for research in nuclear physics (measurement electron-neutron angular corelation during the decay of a free neutron, measuring isotope cross sections for resonance neutrons, investigating γ-rays spectra, ecperimenting with polarised neutrons, studying n-, α-reaction in heavy nuclei), solid-state physics, physics and technology of heavy water reactors.

Research in radiochemistry, in the development of the technology of radiochemical processes, neutrography, radio synthesis of polymers and organic compounds is planned on the WWR-Z reactor in Obninsk.

In Alma-Ata on WWR-K reactor it is planned to carry out work in nuclear spectroscopy and activation analysis.

Research workers in Sverdlovsk think of studying physics of solids on their IWW-2 reactor (magnetic neutronography, dynamics of crystal lattice, radiation defects in solids) and of investigating reactor structural materials.

The IRT reactor in Tomsk will by used for investigations in the solid-state physics, radiochemistry, activation analysis, and radiobiology.

The IRT reactor not far from Moscow will be used both for studying the constants and characteristics of nuclear reactors, the radiation changes in the physical properties of materials, activation analysis, and developing the devices for further nuclear research and also for teaching and demonstration.

After the network of experimental reactors had been established in the Soviet Union, the problem of the day was coordination of investigations on them. In this connection the USSR State Committee on the Use of Atomic Energy and the Academy of Sciences take turns to hold in various towns annual coordinating meetings of the representatives of all reactor centres. At these meetings major lines of scientific work are mapped out for each centre, head institutes named to work on certain problems, experience and information shared, reports on major scientific results for the past period heard and discussed, plans of scientific work drawn up for the next year.

Further progress of experimental reactors in the Soviet Union followed the parth of the development and building of reactors with neutron fluxes of the order of $> 10^{15} n/cm^2 sec$.

The work was conducted along the following lines:

1. A unique experimental reactor SM-2 with high neutron flux has been created.
2. Experimental reactors of a new type - MPR (МИР) and MR for testing fuel elements and materials have been developed.
3. Pulse reactors - graphite PGR (ИГР), fast PFR (ИБР) have been created. The possibilities of the use of pulse graphite reactors for certain physical purposes have been investigated.
4. Various types of specialised reactors with high neutron fluxes for physical research are being studied.
5. The experimental potentialities of the operating reactors are being extended and

finally new reactors are being created.

Main characteristics of certain type of new experimental reactors with high neutron fluxes are given in Table I.

The experience gained during of development and use of experimental reactors in the Soviet Union shows that in many cases it is expedient to build specialised reactors for the definite scientific tasks, rather than multi-purpose reactors. For instance, combination of physical and technical work on the reactor PTR created mutual inconveniences. Increased contamination backgrounds after the failure of the fuel elements under test made physical measurements difficult. That is why the new MPR and MR reactors have been designed as specialised reactors intended only for testing fuel elements and materials. A WWR-Z specialised reactor for studies of the behaviour of chemicals under irradiation was built of late in the Soviet Union. A SM-2 reactor will be used mainly for obtaining transuranic elements. Proceeding from the task projects, it is sometimes expedient to design and build reactors for physical research with a very narrow specialisation intended for research along one, maximum two lines, for example, for research in the solid-state physics alone.

The present paper does not discuss fast-neutron experimental reactors and those which have no relation to science.

I. Research Reactor SM-2

The 50 MW reactor SM-2 I is intended for obtaining transuranic elements, for conducting research into material technology and physics. The reactor has five horizontal, one inclined and I8 vertical channels. It is the first in the wold water-moderated reactor to operate on intermediate neutrons.

The reactor became critical in October I96I and from November I962 it operates at its designed parameters. Its maximum output is 55MW.

In the course of operation with a sub-normal power output and at the designed parameters an extensive amount of research work was conducted; it was connected with the study of the reactor and of its separate units and with a programme of radiating various materials in the experimental channels. The critical mass was investigated for various core with beryllium slugs in the water cavity and so forth. The experiments were carried out on the physical stand and directly in the reactor. The actual critical mass with the water cavity in the centre and without experimental channels amounted to II kg. With the channels the critical mass went up to 13.5 kg. Beryllium slugs in the cavity were used to bring the mass down to 8.6 kg without the experimental channels and to II.2 kg with the channels.

The reactor fuel elements were designed to operate at the maximum heat flux of (5÷6) x IO^6 kcal/m^2/hour. Although according to the thermo-technical calculations the operation of fuel elements under such high heat fluxes was possible, there was danger that in reality they would be beyond reach. Moreover, because of the possible high burn-up of U-235 it had to be checked experimentally. In this connection several fuel elements were tested in the central channel under a heat flux of 6 x IO^6 kcal/m^2 hour up to the maximum (28%) burn-up of U-235 prior to bringing the reactor to operate under the rated power. The tests went off satisfactorily When the reactor operates under the rated power the heat flux of 6 x IO^6 kcal/m^2 hour is reached at the large number of the fuel element and the maximum burn-up in an individual fuel element is as much as 35 per cent.

One of the most difficult problems which arises during the operation of the reactor is a correct distribution of the uranium at the core boundary. Experiments showed that the fuel elements can operate under heat fluxes far in excess of the maximum heat flux of the reactor. Therefore, the main aim such a distribution is not decreasing heat fluxes, but

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that of increasing the average burn-up Calculations prove that without "shaping" the average burn-up of U-235 in assemblies unloaded from the active zone is 6.5 times below the permissible. It means that if, for instance, the permissible burn-up is 36 per cent, the average burn-up will be as little as 6 per cent. When the element distribution was introduced, the average burn-up in the reactor went up- however it is still twice below the permissible.

The problem of the radiation stability of materials is very acute for the high-neutron-flux reactor. Therefore, provision should be made in the design of such reactors for maximum interchangeability of its units.

When the reactor was in the design stage it was decided to use beryllium oxide in the reflector. In the process of operation of the reactor it possible to keep the beryllium oxide samples under constant observation. The accumulated data proves that the integrated flux of 10^{22} n/cm^2 seem to be the limit for the beryllium oxide.

The basic units of the reactor - the cooling system, the overload system, the control system - turned out to be reliable in operation.

The service experience proved the soundness of the basic idea of the design:

I. The thermal neutron flux obtained in the "water trap" was approximately 2.5×10^{15} n/cm^2 at 50 MW; the flux of fast neutrons with an energy of $>$ I MeV in the core exceeded 10^{15} n/cm^2 sec.

2. The maximum power density obtained was 4,500 kW/l (the coefficient of nonuniformity being nearly 3 for the core) and the average power density - 1650 kW/l.

3. The fuel elements proved to be operating smoothly at the thermal flux of 6×10^6 kcal/m^2, a record for the reactor engineering; with the height of burn-up reaching 35%.

At present a plan to boost up the reactor power has been worked out. The core is designed on the basis of the fuel elements made in accordance with the technology which was developed and tested beforehand. The height of the core will increase from 25 to 50 cm. Beryllium oxide in the reflector will be replaced by metallic beryllium in the form of separate interchangeable assemblies. The vessel of the reactor, its circuit, auxiliary systems and structures will suffer no changes.

The power of the reactor will increase from 50 MW to 100 MW and the neutron fluxes in the "water trap" up to $(5 - 8) \times 10^{15}$/ cm^2 sec (depending on the absorption of the samples which will be irradiated in the core) and of the fast neutrons with the energy I MeV up to 2×10^{15} n/cm^2 sec.

2. Research Reactors MPR (ММР) and MR (МР)

Modern loop reactors for testing fuel elements and material studies can be classified as follows:

I. Tank-type reactors (for instance, ETR in the USA, SM-2 in the Soviet Union)

2. Tank-type swimming pool reactors (for instance, GETR in the USA and BR-2 in Belgium)

3. Channel-type reactors (for instance, PTR in the Soviet Union)

The cores of tank-type reactors have better physical characteristics than the cores of the channel-type reactors because they are more homogeneous and contain less structural materials. However at fluxes $\sim 10^{14}$ n/cm^2 the economical effect which comes from the difference in the physical characteristics is meagre.

The swimming pool reactor spells less hazard in case of a accident. Radioactive materials are handled through a layer of water, the fact which makes the work easier and substantially reduces danger for the personnel.

The loop in the channel-type reactors can be installed instead of any of the channels.

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For irradiation the samples can be placed inside the tubular fuel elements in the channels.

However, all the three types of reactors have a number of pronounced drawbacks due to the fact that the access to the core or the interchannel space is rather difficult. This in its turn complicates the research work as well as maintenance and improvement of the reactor.

A fourth variety of loop reactors - swimming pool reactors of the channel-type - have been developed in the Soviet Union. Reactors of this type, MPR and MR, belong in this group and have a number of essential advantages. The core, the channel, inlet and outlet pipes and collectors of these reactors are submerged in the pool with water. The entire core, inter-channel space and reflector included, is easily accessible for conducting experiments. The use of hard moderator (beryllium) placed in the interchannel space make the core big enough for the loops with a moderate number of channels. Single-flow (U-shaped) loop channels and also channels of the "Fields pipe" type may be used in the cores of these reactors. The swimming pool channel reactors are free from the drawbacks of tank and channel-type reactors, and at the same time they have all the advantages of the channel-type loop and of the swimming poll experimental reactors.

At present a I00 MW loop reactor MIR is in the stage of construction in the town of Melekes with a maximum thermal neutron flux of 5×10^{14} n/cm^2 sec in the fuel region and $1,5 \times 10^{15}$ n/cm^2 sec in the central "trap" [2] . The stacking of the core (1 m in height) and of the side reflector consists of beryllium blocks and aluminum-clad graphite blocks. The beryllium blocks are transpiersed with the channels loaded with fuel assemblies which consist of tubular elements with three longitudinal spacer ribs on the surface of each element. Blocks are interspaced with control rod channels. Movable fuel assemblies in some channels can be either inserted into the core from below during the operation of the reactor, as required or pulled out.

I8 cells of the core are intended for setting up loop channels. The control rods and fuel drives are arranged on the movable carriage. Control and fuel rods are lowered for reloading into the extreme bottom position, disengaged from the drives, and the carriage is rolled aside, making space above the core. The fuel is cooled in the reactor single flow channels by light pressurised water. Beryllium and graphite blocks of the core and the reflector as well as the control rods are cooled by the pool water circulating in an independent circuit.

A permanently operating critical assembly made up of spent fuel elements will facilitate the servicing of the multiloop reactor while the initially prepared reliable data for next experiments will make it possible to boost its efficiency.

At the Kurchatov Atomic Energy Institute a MR loop reactor which is the first swimming pool reactor of the channel type, was built to replace the former PTR reactor. The programme of building reactors of this type was initiated in I956. A many year experience accumulate on the loops of PTR reactor came useful in designing a new reactor. The work was so organised as to cut down to a minimum the time between starting the new reactor and shutting down the old one. When the PTR reactor was still in operation, the cellar was enlarged to accomodate new loops. The old reactor was shut down on October I0, I962. After it was unloaded and the loops dismantled, work of building two new pools and of replanning the old loop housings got underway. The accepted structural solutions underwent experimental check-up in the course of designing a new reactor. The installation stage over, the new reactor became critical on December 28, I963 [3] . The rated power being 20 MW (without loops) the neutron flux in the "water trap", a sphere I00 mm in dia., was equal 8.10^{14} n/cm^2 sec.

The varied in height pitch between the channels surrounded by beryllium blocks is one

of the special features of the reactor's design. This made it possible to separate handling parts of the active and loop channels sufficiently and arrange the spacing of fuel assemblies in the core to ensure good physical characteristics of the reactor.

Fuel assemblies placed in the channel's, known as "Fields pipes", are cooled by the pressurised water. The assemblies consist of 5 tubular heat-releasing elements with three longitudinal spacing fins. Eight peripheral cells of the core contain channels with movable fuel assemblies. The samples can be placed for irradiation inside the fixed fuel elements. Beryllium and aluminum-clad graphite blocks constitute the reactor's reflector. Thirteen single-flow U-shaped loops up to 200mm in diameter can be simultaneously inserted into the reactor. The control and safety rod drives and also those of the movable fuel elements are mounted on a mobile carriage. The reactor pool is connected with the storage tank by a lock. The latter has a several million curies γ-irradiation installation utalizing spent fuel.

The reactor components are: the fuel element cooling circuit (first circuit), a circuit for cooling the stacking, systems for oxygen removal and for hydrogen saturation of water purification systems employing mechanical and ion-exchange filters, vacuum system of the first circuit and system controlling channel by channel tightness of the fuel elements.

The reactor is provided with a number of loops utilizing various heat-transfer agents (water-vapour emulsion, water, organic liquids, helium, carbon dioxide). The thermal power of the loops ranges from 500 to 2500 kW.

Maximum fluxes of thermal neutrons in uranium $2.4 \cdot 10^{14}$ n/cm^2 sec and of fast ($E > 0.5$ MeV) neutrons $1.5 \cdot 10^{14}$ n/cm^2 sec along the element axis. The height of the core is 1 m. The maximum thermal flux of the fuel elements - 2.10^6 kcal/m hour. The critical mass is $\sim$ 7 kg. The maximum burn-up of U-235 is 40 per cent.

3. Pulse Reactors

The pulse graphite-moderated reactor PGR (ИГР) [4] was developed for obtaining short-time but very intensive neutron and γ-rays bursts, kinetic and safety studies of the reactor at big reactivity addition and the reactor structure behaviour at high temperatures.

The PGR stacking made up of graphite columns is inclosed in a steel jacket filled up of with hellium and cooled with water on the outside. The core (1.4 x 1.4 x 1.4 m) is made up graphite blocks impregnated homogeneously with enriched uranium (90% by U-235). A reflector 50 cm thick consist of graphite blocks. Uranium impregnated graphite blocks are arranged one above the other in the columns, threaded on cold graphite rods and can free expand. There are clearances between the columns. Central columns are arranged on a table and constitute the mobile part of the core 0.8 x 0.8 m across. The core has also a central experimental channel into which a water cooled sample ampoule is inserted.

The excess reactivity of the cold reactor is compensated for by 13 control rods and by lowering the central part of the core. The control rods are assemblied of hinged graphite tubes filled with pellets of graphite and gadolinium oxide mixture. The lower movable part of the core is the element which prepares the reactor for a neutron burst. When the reactor is started up, the lower part of the structure is lifted into its extreme top position and the control rod is quickly withdrawn, thus causing a burst.

There are no metal parts in the core of the reactor which are liable to limit the heat-up. The reactor has no special cooling system, and therefore the product of the pulse duration on the power is limited only by the heat-up of the core to the permissible temperature determined by the graphite thermal stability.

The reactor components are as follows: the circuit for evacuating the vessel and filling it with helium, the vessel cooling circuit, the circuit cooling the table of the

movable part, the ampoule cooling system and a number of auxiliary circuits.

The reactor has two operating conditions: a) self-regulating burst, b) controlled burst of several seconds or so in duration.

The value of the excess reactivity is 0.22 ± 0.002. The U-235 charge is 7.46 kg. The nuclear ratio U/C I:I0000. The prompt life time is $(1.07 \pm 0.03) \cdot 10^{-3}$ sec.

The integral neutron flux of $1.1 \cdot 10^{17}$ n/cm^2 is obtained under the controlled conditions with the rods completely withdrawn at the mean temperature of the core equal to I800°K and a maximum flux of $1 \cdot 10^{18}$ n/cm^2 under the burst conditions and at the mean temperature of the core equal to I600°K.

No change in the reactor parameters and the graphite stacking had been recorded in the course of its several years' operation. Its systems proved to be safe and reliable in operation, providing a whole range of operating conditions for a test programme.

In the paper [5] the use of the pulse reactor for physical research are considered and particularly for studying interaction of the neutrino with a substance when the ratio of the cosmic ray and the netural radioactivity background and the effect during measurement is great. The pulse operation of the reactor cuts down the value of the ratio between the background and the measured effect.

A number of varieties of the pulse reactors operating as antineutrion generators was analysed on the basis of the developing and operating experience of the PGR reactor accumulated in the Soviet Union. In all the cases it is assumed that the cores are made up of graphite blocks impregnated with uranium by the method which was used for the PGR reactor. Beside the dimensions, the reactor differs essentially from the PGR reactor by the fact that the graphite blocks are provided with coolant pipes to cut down sharply the time of cooling of the stacking.

A 600 MW reactor with a thermal flux of $1.25 \cdot 10^{13}$ joules in pulse will make it possible to measure the scattering cross section of the soft antineutrino emmitted by fission fragments on electrons. According to the calculations this reactor will be I300 times bigger in volume than the PGR reactor. It will have 5,000 tons charge of graphite, I,000 kg charge of U-235 and will be provided with a 260 MW heat removal system.

To obtain hard antineutrino it is expedient to activate in the reactor extra pure litium-7. 25 tons of radiated litium-7 will serve as an antineutrino source. In this case the dimensions of the reactor and the average power decrease considerably: the weight of graphite by 5 times, average power - two times, U-235 charge - 2.5 times and pulse heat release - five times.

The dimensions and power of the reactor can be further reduced only by passing over to a more complex design. After being radiated by the pulse 1 sec in duration it should take lithium the same time to get to the collector. Every 2.5 hours (intervals between the pulses) lithium emits an antineutrino flux of 1.5×10^{15} 1/cm^2 to be used in the measuring apparatus. The average power of the reactor in this case will be I75 MW, weight of graphite - 500 tons, U-235 charge - I75 kg, pulse heat release - 0.11×10^{13} joules.

All the above discussed types of reactors provide practically similar conditions for experiments.

A PFR (ИБР) pulse fast-neutron reactor was started up in the town of Dubna in I960 The reasearch work conducted on this reactor includes: a) the study of liquids and solids with the help of scattered neutrons; b) neutron spectrometry (the study of neutron cross sections and of resonance levels of atomic nuclei). The reactor operates with periodic pulses with half-width of 36 to 40 microsec and frequency ranging from 3.3 to 83 pulse/sec. Its mean thermal power is maintained constant. In I964 it was increased from 1 to 3 kW. The maximum instantaneous power at 3 kW and frequency of 3.3 pulse/sec is 23 MW.

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The neutron global intensity at a pulse maximum is 1.3×10^{18} n/sec.

A special feature of the reactor is a device which periodically changes its reactivity. It consists of a steel disc rotating with a great speed, with a slug of U-235 pressed into it near its periphery. When the disc rotates, the slug passes between the assemblies with plutonium rods (a stationary part of the core) bringing the reactor for a very short period of time to the above critical state.

Seven horizontal channels two of which operate in the 100 to 1000 m flight distance range serve to extract neutron beams.

Great duration of the burst (36 microsec) is a drawback of the reactor when it is used as a neutron source for spectrometry experiments in the resonance region. It can be cut down sharply by employing the reactor in the sub-critical operating regione as a multiplier of fast neutrons injected into the reactor by an external source - an electronic accelerator microtron. The microtron electronic beam will be focused at the uranium target placed in the channel inside the fixed part of the core for generation of photoneutrons. When the reactor is run as the multiplier, the improvement in counting rate is of the order of 1 or 2, resolution being the same, and, moreover, a better by an order resolution may be achieved. This concerns experiments with resonance neutrons. It is more advantageous to work with cold and thermal neutrons without the microtron, since the burst duration of thermal neutrons is determined by the lifetime of neutrons in the moderator.

The three years ' operating experience has shown that the PFR reactor is a reliable and convenient installation providing ample possibilities for neutron research. There are also a number of ways to improve its characteristics.

4. Specialised Reactors For Physical Research

At present the neuclear reactor is employed as a neutron and γ-radiation source for various research work in the nuclear physics, physics of liquids and solids and also chemical and biological studies. This broad scope of research work, as a rule puts forward a number of requirements which are quite at variance with one another and which it is unable simultaneously to cope with. Therefore, a modern reactor cannot be a universal facility, but should be designed for a certain range of research.

Some of the requirements can be cited on the basis of the experience accumulated in the Soviet Union, which an experimental reactor should satisfy when employed in the researches on physics. It is desirable to have in the reactor core a neutron flux of the order of $\sim 10^{15}$ n/cm^2 sec and in the experimental beam yield at the reactor biological shielding, somewhere about 10^{11} n/ cm^2 sec. This flux ratio in the core and channels calls for a particularly compact biological shielding. The number of horizontal experimental channels should be limited to exclude their mutual effect upon each other and the effect of the reactor control systems on them. Each channel should be equipped for a certain narrow range of research work. The study of structure and dynamics in solid-state physics requires channels with a big-neutron thermal flux and with a small admixture of fast neutrons and γ-irradiation. High-thermal neutron fluxes are attained by means of channels with a big angular divergence. In certain cases channels should be provided with special cavities made in biological shielding for experimental instrumentation, such as the monochromator unit of the neutron diffractometer, crystal filter, etc.

Experiments involving capture γ-rays require cavities in the core with high neutron fluxes screened from γ-irradiation of the core and the structural elements of the reactor.

The reactor should be provided with several through channels including tangential ones for putting into the core specimens and some experimental equipment. These channels can be used particularly effectively for studying the capture γ-irradiation and for

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experiments with cold and thermal neutrons using a cooled or heated moderator.

For biological studies irradiation should be separated either into n- of -type and certain energy groups of neutrons singled out. All life science studies should be made in thermobaro-chambers; this calls for big volumes with sufficient isothropic distribution of neutrons and γ-irradiation.

As a rule, neutrons of a definite spectrum - cold, thermal, resonance, fast - are used in experiments. Hence, the design of the reactor should permit of forming a neutron spectrum in the pre-set energy interval.

For studying changes in physical and mechanical properties of materials under irradiation, a reactor should be provided with low-temperature loops operating at as low a temperature as that of helium. The arrangement of rather bulky systems inside the core, cooled down to very low temperatures, is a very difficult problem from the technical point of view, a problem connected with the necessity of heat-removal, maintenance of the required temperature and with the behaviour of materials during irradiation. To meet these requirements, the core when the equipment for physical experiments is arranged inside it, should be quite big, provided that this does not essentially affect the operation of the reactor.

Here is a variant of the reactor design suggested by Y.Nikolayev and A.Chervyatsov which may satisfy the above requirements. It is the reactor with a very low concentration of fissionable material in the core which provides a maximum thermal flux of $\sim 10^{15}$ n/cm^{2}sec, at a relatively moderate power and with a big volume which is very convenient for experiments. Heavy water is a moderator and a coolant. The fuel plates consist of highly enriched uranium and metallic beryllium The concentration of U-235 may be lowered to 1 g/l due to the use of materials in the core with very low absorption cross sections; the charge is ~ 1 kg of U-235 and the core volume ~ 1 m^3. A sufficient number of neutron beams of lagre diameter with a neutron flux yield of 10^{11} n/cm^2 sec can be obtained in such a reactor.

In certain cases the type of experimental reactor and its operating duty may depend not on the character of the research work, but rather on the method of carring out it. As is known, the flight time method is one of the basic methods of studying the interaction of monochromatic neutrons with nuclei and with substance in a condensed state. In this method charged particle accelerators and thermal neutron reactors are widely used as neutron sources. It is quite evident that the use of a stationary thermal-neutron reactor is not justifiable in this case, since the neutron flux is exposed only 1 per cent of the time; while 99 per cent of the time the reactor is a source of the background noise. Hence, the problem is to develop a special reactor operating in pulse regime. However, even in pulse reactors (PFR is this kind of reactor) the pulse lasts several tens microseconds which is far from being sifficient to ensure resolution efficiency in the region of resonance neutrons and requires additional means to decrease pulse duration. Therefore, pulse reactors are most expedient in conducting experiments with thermal and epithermal neutrons, first of all for studying the dynamics and structure of the condensed state of a substance and the process of neutron thermalisation.

The thermal neutron pulse reactor makes it possible to increase considerably the neutron flux in a pulse. At a relatively moderate average power of 10 to 20 MW a pulse flux can be obtained up to 10^{16} n/cm^2 sec with a frequency of 100 pulses per second and a pulse duration of 200 microsec. This type of reactor was suggested by V.Mostovoi, S.Fainberg and Y.Shevelyov.

Thus we shall have a 20-time gain in power as compared with a stationary one. Obviously, neutron pulses of this duration cannot be used directly in measurements by the flight time method. Beam choppers synchronized with the reactor should be used to

provide neutron pulses of the required duration.

Naturally, it is very difficult to meet all the requirements of experimental research work. However, in selecting the type of an experimental reactor and in designing it, taking them into account will help to enlarge and refine its experimental potentialities.

5. Extending the Scope of Experimental Potentialities of the Operating Reactors and Developing New 5MW Reactors

Some of the already existing reactors don't satisfy requirements of new experiments and increasing their neutron-physical parameters becomes the question of the day. In certain cases it is expedient to remodel already operating reactors to extend the scope of their experimental potentialities since reconstruction can be carried out in less time and at a lower cost than building new reactors. We, in the Soviet Union, have the required experience. In the paper [7] it was described remodelling of operating reactors of the PTR, WWR-2 and HWR type.

The reconstruction of the IRT reactor operating since 1957 is today underway at the Kurchatov Institute of Atomic Energy. The power of the reactor was boosted by using new fuel assemblies consisting of three coaxial tubular elements square in section with a greater cooling surface instead of fuel rod assemblies. Any of these tubular element assemblies can be used for irradiating experimantal samples of for inserting into them control rod channels.

The reactor's power is increased to 4MW, since most of the old technological equimpment is retained and only a few changes made. The maximum flux in the new reactor in the uranium core is 6.10^{13} n/cm^{2}sec (instead of 3.10^{13} n/cm^{2}sec), and in the "neutron trap" when four assemblies are extracted from the centre of the core the flux reaches 2.10^{14} cm^{2}sec.

An installation for obtaining beams of "cold" neutrons replaces the old thermal column, the number of experimental channels in the core and their size are increased and a tangential through channel is made.

Presence of the induced radiation in the structures adjacent to the core that are not to be replaced and in the steel plates of the thermal biological screen shield is the chief difficulty for the developing of the "cold" neutron source and for reconstruction as a whole. Therefore, a number of dismantling operations can be carried out only from a safe distance.

Design for increasing the power of the reactor WWR-C and expansion its experimental potentialities are of special interest for the countries in which reactors such type have been built with the help of the Soviet Union. In one of the variants rod fuel assemblies are replaced by new five-tube elements possessing all the advantages described above. The use of new elements requires no additional changes in the core. Remodelling increases the reactor power from 2 to maximum 8MW and boosts maximum neutron flux by three time from 2.10^{13} to 6.10^{13} n/cm^{2}sec., the flux in the "neutron trap" upon the extraction of four adjacent fuel elements is 2.10^{14} n/cm^{2}sec.

The loops which were added to the WWR-2 reactor in Moscow serve for studying radiolysis of various organic coolants and their regeneration. A 300kW organic moderated reactor OR (OP) was created instead of the multiplier. A neutron convertor was developed for investigations neutron spectrum in various lattices to obtain the required spectrum; the coverter is placed between the core and the lattice.

A number of structural changes of separate units were introduced on the reactor IRT in Minsk [8], to expand its experimental potentialities. In order to conduct work in the

loops, a "neutron trap" was made in the core centre for loop channels of different types A water cavity in the core center has brought the maximum flux to IO^{I4} n/cm^{2}stc. Some experimental horizontal channels were remodelled for the experimental work in the solid-state physics, nuclear spectography and for various other investigations, and additional "hot" chamber made in the body of the reactor's concrete shield.

An indium-gallium-tin radiation circuit with average power of 48 kg.eqv. radium (γ -radiation source) created in the IRT reactor in Riga, that considerable enhanced the experimental potentialities of the reactor. The circuit is employed for conducting experiments in radiation physics, chemistry, radiobiology, etc. It is adopted for semi-industrial irradiation of samples in the volume of up to 90 e with the dosage rate from 0.4 to 0.6 milliroentgen and for example for irradiation of polyethylen radio-engineering articles in order to increase their heat stability. The reactor is provided with an electromagnetic rabbit for transporting containers with irradiated samples; its thermal column is remodelled for research work in neutron scattering and some of its horizontal channels are adopted for biological experiments and research in radiation physics. The reactor is also provided with an additional chamber in the concrete shielding.

After remodelling the loops for studying physical and chemical properties of substances under the action of nuclear radiation at low temperature, indium-gallium irradiation circuit and an installation for oil-chemical research in gaseous, vapourous and liquid phases under irradiation were installed in the IRT reactor in Tbilisi.

The power of the Kiev WWR-M reactor [9] was increased from IO to I2 MW without any additional structural changes, simply by introduction of a new system of outgassing and desalting of water in the first cooling circuit.

A maximum flux of $3.IO^{I4}$ n/cm^2 sec was obtained in the neutron flux of the reactor WWR-M in Leningrad IO after a number of improvements hos been made which raised tho reactor's efficiency. They include: a closed deaerating circuit, added along with a new water purification system and four additional channels in the reactor's shielding for conducting experiments with tangential beams.

In the heavy-water reactor HWR in Moscow after replacement of a 2% inriched uranium fuel by a new with 80% uranium enriched with isotop-235, a maximum flux of $4.IO^{I3}$ was obtained instead of $2.5.IO^{I3}$ n/cm^{2}sec., the power of 2500 kW remaining the same, the neutron-flux yield of the horizontal experimental channels was doubled and a new vertical holes were provided inside the circular fuel elements for the material irradiation.

Side by side with the remodelling of the already existing operating reactors new 5MW reactors were developed: water-moderated reactor of the swimming-pool type, intended basically for the experiments in the field of the solid-state physics and for studying the stability and strenght of various materials subjected to irradiation.

The core 500mm in height is made up of assemblies cosisting of 36% enriched uranium fuel elements. The initial charge is 5.5kg of U-235. Maximum flux in the core centre (with water cavity) is $2.IO^{I4}$ n/cm^{2}sec. The fast neutron fluxes - 6 to 9 $.IO^{I3}$n/cm^{2}sec ($E > 0.7$MeV). The reactor is provided with two tangential channels, five radial channels, a channel with "cold" neutron beam and with a number of vertical channels. Four loop (isothermal) channels with self-contained circuits are provided for testing radiation damage in various nonfissionable materials in different media. Water in the new colling circuit is circulated in the core with the help of the vertical acial pump into the heat-exchanger installed in the reactor tank.

A newly designed reactor IRT-5000 utilizes part of the equipment of the standard type reactor IRT-2000. The core, submerged in the pool, after the design of the IRT-2000 reactor with a compact biological shielding, increases the yield of the neutron flux intensity of the horizontal expiremental channels. The reactor core dimensions were

increased in order to raise the power and extend the reactor's experimental potentialities: height from 500 to 600mm, a number of cells accomodating fuel assemblies and holes in the reflector from 48 to 72. Fuel assemblies cosisting of 3 tubular fuel elements square in section (of the IRT-M type), will be employed in the reactor and graphite aluminum-clad and beryllium blocks, in the reflector. Maximum flux in the IRT-5000 reactor will be 6.10^{13} n/cm^{2}sec. in the "neutron trap". The number of vertical channels is increased. The reactor is provided with an installation producing a beam of "cold" neutrons and with a new cooling system with the downward flow of the coolant in the core maintained with the help of the ejector.

Tabl I

BASIC CHARACTERISTICS OF SOME OF THE NEW EXPERIMENTAL HIGH-NEUTRON FLUX REACTORS

Reactors	SM-2* (CM-2)	MPR (МИР')	MR (MP)	PGR (ИГР)	PFR (ИБР)
Power, MW	50	I00	20	10^5(inst)	23 (Inst)
Maximum thermal neutron flux in uranium, n/cm^2 sec	-	5.10^{14}	$2.4.10^{14}$	-	-
Flux in a trap or in the burst maximum, n/cm^{2}sec	$2.5.10^{15}$	$1.5.10^{15}$	8.10^{14}	1.10^{18}	-
U-235 charge,kg	I8	I0	7.0	7.46	-
Fuel enrichment,%	90	90	90	90	-
Core volume,l	30	I200	600	2750	-
Maximum specific power, kW/kg fuel	9	20	9.5	I3400	-
Maximum power density, kW/l	4500	280	I60	36000	-
Moderator	H_2O	H_2O+Be	H_2O+Be	Graphite	-
Core height,mm	250	I000	I000	I400	-

* After remodelling the SM-2 power will be increased to I00MW, while the maximum thermal-neutron flux - to $5-8.10^{15}$ n/cm^{2}sec.

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Примечание: I–6 и 8–I0 доклады на Ш Международную конференцию по использованию атомной энергии в мирных целях и 7 – доклад на П Международную Конференцию по использованию атомной энергии в мирных целях.

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